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A DISCUSSION AND CORRELATION OF CERTAIN SUBDIVISIONS OF THE COLORADO FORMATION

A FAIRLY accurate correlation of the subdivisions of the Colorado formation in the central-interior province is not difficult. Although the work done in the different areas of the province has been largely independent, yet divisional lines are not strikingly inharmonious. Points of separation are more easily determined in certain areas than in others. In specific parts of the province confusion in regard to divisional lines seems to have arisen, due to misinterpretations of a palæontological nature, while in other parts the confusion seems to be due to lithological similarities. The points involved are, on the whole, minor ones, and, perhaps, are not worthy of any very elaborate discussion. Nevertheless, stratigraphical geology is, at its best, complex, and therefore should receive every additional contribution which will tend to relieve its comlexity.

The Colorado formation has not been studied as thoroughly and systematically as is desired, yet a study has been made of a sufficiently large number of areas to warrant the establishment of more general division lines. The areas of the central-interior province which have been studied somewhat in detail are: The southeastern Colorado area, the Black Hills area, the eastern Dakota area, the Iowa-Nebraska area, and the Kansas area. Since I am more familiar with the detailed stratigraphy and palæontology of the last-named area I will discuss it and use it as a standard by which to correlate the other areas.

In the Kansan area two principal groups have been recognized for the Benton series. These groups are, the lower or Limestone group and the upper or Shale group. The division is based primarily on lithological grounds as the names indicate. The Limestone group admits of five subdivisions, such divisions being made on either palæontological, lithological or economic conditions. The subdivisions are: The Bituminous Shale, the Lincoln Marble, the Flagstone Beds, the Fencepost Beds, and the Inoceramus Beds. The Shale group has two divisions, the Ostrea Shales and the Blue Hill Shales. The Niobrara series is divided into the Fort Hayes Limestone and the Pteranodon group, the latter being further divided into the Rudistes Beds and the Hesperonis Beds.

FORT BENTON

The bituminous shale.—Although I have named these beds as one of the subdivisions of the Limestone group I prefer to discuss them separately for convenience of correlation. The Bituminous shale is a moderately compact argillaceous shale which in some localities is somewhat calcareous. The prevailing color of the shales at the base of the beds is dark blue, which passes to light gray at the upper limit. The beds contain the remains of a marine fauna, since plesiosaurs' bones, sharks' teeth, and impressions of Inoceramus are found in them. The maximum thickness of the stratum is not more than twenty-five or thirty feet.

In the Arkansas valley in Colorado its stratigraphical equivalent, the Graneros shales,[1] reach a thickness of 200 feet. In the Huerfano area[2] these shales have a thickness of 100 feet. Near Sioux City, Iowa, and Ponca, Nebraska,[3] a bed of shales, having a thickness of forty feet, occupies the same geological horizon and possesses primarily the same characteristics. In the Black Hills area near Buffalo Gap these shales have a thickness of more than twice that of the Eastern area, being in the neighborhood of 100 feet in thickness. The stratum appears to be very persistent, occurring in all the known areas of the central-interior province. And although it varies much in thickness its faunal and lithological characteristics are remarkably uniform.

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[1] GILBERT, G. K., The Underground Waters of the Arkansas Valley in Eastern Colorado, Seventeenth Ann. Rept. U. S. Geol. Surv., 1896.

[2] STANTON, The Colorado formation and its Invertebrate Fauna, Bull. U. S. Geol. Surv., 1893.

[3] CALVIN, The Relation of the Cretaceous Deposits of Iowa to the Subdivisions of the Cretaceous proposed by Meek and Hayden, Am. Geologist, Vol. XI.

The Limestone group.—The Limestone group is recognized in all the areas except the Iowa-Nebraska and Eastern Dakota areas. Subdivisions have not been designated for the group in any of the areas except the Kansan. Although the subdivisions are persistent the divisional lines are arbitrary for the beds grade into each other. The Lincoln Marble is more easily differentiated on both palæontological and lithological grounds. It has a remarkably interesting and unique fauna. In the shallow marine waters where its beds were deposited, foraminifera, corals, and oysters were associated with sharks, fish, turtles, and saurians. The rock is composed almost wholly of foraminiferal remains, in which are imbedded sharks' teeth, fish teeth, shells, and other animal remains. So abundant are the teeth in certain portions of the rock that it gives a reddish hue to the surface on which they have been rendered visible by weathering.

The beds are composed of thin layers of a compact close-textured limestone, having an average thickness of three or four inches, and susceptible of moderate polish. On account of the last-named characteristic it is called, locally, marble. The limestone layers are separated by thin beds of shale of about the same thickness. The assumption that these beds are of shallow water origin is based on the presence of quantities of carbonaceous matter in the limestone and the highly carbonaceous character of the intercalated shale beds. Numerous fragments of fossilized trees and charcoal have been discovered in the beds in the Kansan area.

The Lincoln marble is notably persistent in the Kansan area. The same is true of the Black Hills area. In the latter area the layers of limestone are somewhat arenaceous, but the faunal characters are similar, as fish teeth and saurian bones have been noticed. It is presumable that when a careful study is made of the Benton stratigraphy in other parts of the province that the Lincoln marble will be differentiated. Such is not so likely to be true in the case of the other subdivisions of the Limestone group, since the criteria are not so pronounced.

In the Iowa-Nebraska area, according to descriptions given of that region, the Benton limestone group seems to be entirely wanting. This may be due to a misunderstanding in regard to the proper position of the division line between the Benton and the Niobrara. The following is a description of the Benton in that region.[1] "Shales are more or less unctuous to the feel, somewhat variable in color and texture, containing remains of saurians and teleost fishes, the upper beds sometimes bearing impressions of *Inoceramus problematicus;*" while the Niobrara which rests upon the above described Benton shales is described as follows: "Calcareous beds consisting of chalk and thin bedded limestones, containing shells of *Inoceramus problematicus*, *Ostrea congesta*, and teeth of *Odotus*, *Ptychodus*, and other selachians; thickness, thirty feet."

It is not improbable that a part of these thirty feet of so-called Niobrara should be assigned to the Benton, since, in speaking further of the beds, the author says: "These (beds) consist in part of soft chalky material and in part of fissile limestone that divides under the hammer or on exposure to the weather, into relatively thin laminæ crowded with detached valves of *Inoceramus problematicus*."

The above describes exactly the Inoceramus beds of the Benton in the Kansan area. In that area *Inoceramus labiatus*, syn. *problematicus*, makes its appearance in the upper Bituminous shale beds, and continues to increase in numbers until the Inoceramus beds are reached, where it attains the acme of its abundance. It then declines in numbers to the Blue Hill shale horizon, where it disappears altogether, and if it reappears at all in the Niobrara it is very rare.

The geological range of the species is confined to the lower Benton, and although its zone appears to be narrow its geological distribution is exceedingly wide, as it is reported from nearly all known Cretaceous areas. Mr. Gilbert[2] mentions it as the characteristic fossil of the Benton limestone in the eastern Colorado area, and also speaks of its abundance in certain layers. *Inoceramus labiatus* has been confused in certain areas with *I. deformis* and other species of the same genus. This confusion has arisen on account of its reported association with *Ostrea congesta*. *Ostrea congesta* occurs in the Benton, where it is found adhering to a large nearly flat *Inoceramus*, but is never found adhering to the much smaller species, *Inoceramus labiatus*. In fact, it is rarely found associated with that species. *Ostrea congesta* occurs also in the Niobrara. It is here found attached to *Inoceramus pennatus*, *I. concentricus*, *I. platinus*, *Radiolites maximus* and other large shells. *Inoceramus sp.*, to which the ostreæ of the Benton are attached, resemble *Inoceramus platinus* of the Niobrara, but on account of the extreme brittleness of the Benton shell, due to its transversely fibrous structure, whole specimens cannot be obtained for examination.

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[1] CALVIN, loc. cit.

[2] Loc. cit.

But there is a distinction between the forms of the adhering ostreæ. *Ostrea congesta*, var. *Bentonensis* is a small thin subtriangular shell which, if permitted to grow uninterrupted, is almost flat. The upper valves are so thin that they are rarely preserved. *Ostrea congesta*, var. *Niobraraensis* is a larger, thicker shell, with the lower valve more capacious, and possessing near the hinge area well-marked vertical lines of muscular attachment. The upper valve is also thick, and in many specimens possesses adhering forms of the same species. The differences may not be marked enough to be considered specific differences, but they are sufficiently well developed to distinguish the two forms. It is well to bear in mind then that there is a species of *Inoceramus* in the Benton which possesses adhering forms of ostreæ, and that there is a similar species in the Niobrara possessing them, and that therefore *Ostrea congesta* adhering to *Inoceramus* cannot be taken as a criterion for either group unless the ostreæ are properly differentiated.

The shale group.—Resting upon the limestone group is a bed of shales called the Ostrea shales on account of the abundance of that fossil in them. These shales are argillaceous, so much so in places that they might with propriety be called clay, and are variable in color. The prevailing color is dark blue. Here and there in the shales are thin beds of limestone containing *Inoceramus labiatus* and species of cephalopods. *Ostrea congesta*, var. *Bentonensis* attached to *Inoceramus sp.*, is the most abundant species. Fish teeth, sharks' teeth, and pavement plates and fossil wood containing species of *Parapholæ*, also occur. Near the upper limit the shales contain a species of *Inoceramus* with *Serpula plana* attached. The thickness of the Ostrea shales in the Kansan area is 150 feet. They are the stratigraphical equivalent of the lower Carlile shales in the eastern Colorado area. The Black Hill area possesses a bed of shales twenty or thirty feet in thickness, which is stratigraphically and palæontologically equivalent to the Ostrea shales. Specimens of *Serpula plana* and *Inoceramus labiatus* were found in an outcrop of the shales on Hat Creek, a southern branch of the Cheyenne River. The Ostrea shales in this area are somewhat arenaceous, and the prevailing colors are blue and light yellow. The Ostrea shales are wanting in the Iowa-Nebraska and eastern Dakota areas.

The Blue Hill shales.—The Blue Hill shales form the upper zone of the shale group. They are dark or slaty colored shales which, under the influence of weathering, break up into very fine, chaff-like fragments which are so light as to be moved about somewhat easily by the wind. On account of their fine, laminated appearance the shales are sometimes called paper shales. They are unfossiliferous and homogenous, except in the upper third. This zone has numerous argillaceo-calcareous concretions called septaria imbedded in its shales. Some of these concretions possess the cone-in-cone structure, while others are formed of concentric layers. Fissures in others of the concretions have been filled in by sedimentation with calcite which ranges in color from white to claret. These are the true septaria. Many of the concretions are highly fossiliferous. The following species have been collected from them: *Scaphites larvæformis*, *S. vermiformis*, *S. warreni*, *S. ventricosus*, *S. mullananus*, *Rostellites willistonii*, *Pri-*

onocyclus Wyomingensis, *Placenticeras placenta*, *Inoceramus undabundus* and *I. tenuirostratus*.

In the Kansan area the Blue Hill shales have a thickness of 100 feet. The upper Carlile shales form their stratigraphical equivalent in the Colorado area. The septaria zone occurs in relatively the same position in the Carlile shales, and presents approximately the same lithological characteristics. The total thickness of the Carlile shales is from 175 to 200 feet, including the upper and lower beds, the equivalents of the Blue Hill and Ostrea beds. In the Black Hills area a bed of shales thirty to forty feet in thickness, bearing calcareous concretions of the cone-in-cone structure is the stratigraphical equivalent of the Blue Hill shales. The Blue Hill shales as well as the Ostrea shales have no equivalent in the Iowa-Nebraska and eastern Dakota areas.

THE NIOBRARA

The division line between the Benton and the Niobrara in the Kansan area at least is not an arbitrary one. Lithologically it marks a change from dark argillaceous shale to comparatively pure chalk of remarkable whiteness, scarcely compact enough to deserve the name limestone. The change is one of abruptness, there is no transition zone. The shale does not appear again. A massive stratum of limestone rests upon the dark shales, and there is no intermediate layer, part chalk and part shale. Palæontologically the change is marked by the ushering in of an almost entirely new fauna.

Two principal divisions of the Niobrara are recognized in the Kansan area. These are the lower or Fort Hays limestone and the upper or Pteranodon beds. The division may be said to rest on both lithological and palæontological grounds. The Pteranodon beds are further subdivided into the Rudistes and Hesperonis beds. This division is made on purely palæontological evidences.

The Fort Hays limestone.—The Fort Hays limestone is in massive layers of from two to four feet in thickness, and the total thickness of the bed is fifty to sixty feet. When taken from the quarry it is very soft and easily cut and carved into any desired shape. It hardens somewhat on exposure. The lower portion, except for the minute cocoliths and foraminiferæ is largely unfossiliferous. The upper portion contains many species of invertebrates.

In the Colorado area the lower fifty feet of the Timpas beds is the equivalent of the Fort Hays. The zone is described as being composed of layers of a compact, rather fine-grained limestone of a light gray color which becomes creamy white on weathered surfaces. The layers are from a few inches to three feet in thickness, and are separated by thin beds of shale usually one or two inches thick.[1]

In the Black Hills area the position of the Fort Hays is occupied by a bed of shales containing a layer of limestone two feet in thickness. In the Iowa-Nebraska area it seems probable that the Fort Hays beds rest upon the Benton limestone, but the line of separation may be difficult to establish. In the eastern Dakota area the equivalent stratum reaches a thickness of 130 feet.

The Pteranodon beds.—The upper division of the Niobrara comprises the true chalk of the Kansan area. The chalk varies in color from a light blue through lavender, yellow, and buff, to red and orange. Under fresh exposure it presents the appearance of a blue shale, and has often been taken for such. The freshly exposed beds, however, under the weathering influence of air and water, soon change their shale-like appearance and blue color. The change in color is probably due to a chemical change in the iron compounds in the chalk. Chert beds occur in some places interstratified with the chalk. These are only of very local occurrence, however. The chalk is used to some extent as a mineral pigment in the manufacture of paint. Fossil wood is not of rare occurrence in the chalk, and it is frequently found pierced with the shells of *Parapholæ.* Fragments of amber[2] have been obtained from some of the specimens of fossil wood. Charcoal also occurs in the chalk as well as in the Benton limestone. Nodules of pyrite are abundant in some outcrops.

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[1] GILBERT, loc. cit.

[2] WILLISTON, The Niobrara. Kan. Univ. Geol. Surv., Vol. II.

The lower Rudistes beds present a varied and extensive invertebrate fauna. The Hesperonis beds contain fewer invertebrates, but a vastly greater number of vertebrates than the lower Rudistes beds.

The upper 125 feet of the Timpas beds is probably the equivalent of the Rudistes beds, while the Apishapa beds are the equivalent of the Hesperonis beds in the Colorado area. In the Black Hills area the position of the Pteranodon beds is occupied by a bed of shales with a thin bed of limestone. The beds are wanting in the Iowa-Nebraska and eastern Dakota areas. In the following table, which is intended to show the relation of the different subdivisions in the representative areas, the eastern Dakota area is omitted, as it does not differ materially from the Iowa-Nebraska.

		Kansas area		Colorado area		Black Hills area	Iowa-Nebraska area
THE COLORADO FORMATION	NIOBRARA SERIES	Pteranodon beds, 275′	Hesperonis beds, 150′	Apishapa beds, 200′		Shale, limestone, 150′	Wanting
			Rudistes beds, 125′	Upper Timpas, 125′		Shale, limestone, 200′	Wanting
		Fort Hays limestone, 50′ to 60′		Lower Timpas, 50′		Limestone, 2′ to 4′	Chalk, limestone, 40′
	BENTON SERIES	Shale group, 250′	Blue Hill shales, 100′	Carlile shale, 200′	Upper Carlile	Shale, 30′ to 40′	Wanting
			Ostrea shales, 150′		Lower Carlile	Shale, 20′ to 30′	Wanting
		Limestone group, 40′ to 50′		Greenhorn limestone, 25′ to 40′		Limestone, 10′ to 15′	Wanting (?)
		Bituminous shale, 20′ to 40′		Graneros shale, 200′		Shales, 100′	Shales, 40′

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